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Kinetics modeling of the drying of chickpea (*Cicer arietinum*) with solar energy.

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Abstract

Chickpea, (*Cicer arietinum*) is commonly known as garbanzo is a type of pulse, with one seedpod containing two or three peas. There are two main kinds of chickpeas: Desi, which has small, darker seeds and a rough coat, cultivated mostly in the Indian subcontinent, Ethiopia, Mexico, and Iran; and Kabuli, which has lighter coloured, larger seeds and a smoother coat. In 2011 in Mexico, 132 000 tons were produced for human consumption. The results observed in this work show that it is possible to dry chickpeas using an indirect-type solar dryer. The studied chickpeas came from Guanajuato State, in Mexico, and had an average moisture content of 0.52 kg water/kg dry mass (dm). At the end of the drying process this content was of 0.02 kg water/kg dm. The required time to accomplish this drying quality was 40 hours in April and 32 hours in May, 2012. The empirical model that best represented the process was the exponential one, with the three imposed conditions

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1. Introduction

Chickpea, (*Cicer arietinum*) is commonly known as garbanzo; the plant grows to between 20 - 50 cm high and has small feathery leaves on either side of the stem. Chickpeas are a type of pulse, with one seedpod containing two or three peas. There are two main kinds of chickpeas: Desi, which has small, darker seeds and a rough coat, cultivated mostly in the Indian subcontinent, Ethiopia, Mexico, and Iran; and Kabuli, which has lighter colored, larger seeds and a smoother coat, mainly grown in Southern Europe, Northern Africa, Afghanistan, Pakistan, Chile, and India. In 2011 in Mexico, 132 000 tons were produced for human consumption in approximately 90 000 cultured ha [1].

Drying is energy-intensive and has a negative environmental impact due to fact that most of the thermal energy needed is obtained by combusting fossil fuels. From 12–25% of national industrial energy

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consumption is attributed to thermal dehydration in industrial nations [2]. As global economies prosper, the demand for energy for drying will increase. Thus, there is need to understand this operation well and to ensure that it is carried out as efficiently as possible within the economic constraints of the market. It is also important to keep abreast with the current drying technologies, as well as the emerging new ones.

Drying has been used from immemorial times to preserve food products. Open-air drying is the most commonly used method, especially in tropical and subtropical countries. However, several disadvantages are usually confronted [2]: product damage caused by rodents, birds and insects; product degradation due to direct exposure to sun light, rain, storms, and dew; contamination with particles and gases due to air pollution; possible cracking of the product and loss of germination capacity; quality reduction during storage due to inefficient or no-uniform drying. Open-air drying is also a common practice for chickpea, taking between 15 to 20 days in summer time to attain complete drying of the product. Thus, alternative drying processes, such as those based on solar energy may represent important savings and effective profits, if these drying times can be cut off with the corresponding benefits in the product quality.

Several solar devices for food drying have been constructed and evaluated; for instance, a cabin type dryer has recently been used to dry vegetables such as zucchini, green pepper, beans, and onion [3], at 46 °C, using up to 90 effective sun hours for beans. Corn was also dried in a similar drier, requiring 75 hours of sun to dry 10 kg of product at 42 °C [3]. The drying of pineapple has also been studied using a combined biomass-solar system [4]. Such device uses the alternate source of energy (biomass) to cover the night periods in order to have a continuous drying system. The product temperature was kept constant at 65 °C, requiring 39 hours for total drying.

In this work the drying of chickpea, using a solar dryer with natural convection was studied. The drying process was monitored daily from 9:00 to 18:00 hours, during the months of April and May, 2012. The chickpea was dried in 40 hours in April, while in May it took 32 hours. The numerical model that best described the drying process was the exponential.

Nomenclature

a, b, c, n constants

k drying constant (numerical models)

MR moisture rate

M wet mass in time t

M_e equilibrium mass

M_0 initial mass

t time

2. Drying kinetic of chickpeas

In the drying process of vegetable products it is important to determine the model that describes such process, which is obtained from experimental data [5]–[10]. Several models that describe the moisture relationship (MR) of a product as a function of time have been developed. The most used numerical models are presented in Table I.

The moisture relationship (MR) is defined as,

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

Where M is the moisture content at time t , M_0 in the initial and M_e is the equilibrium moisture content, whose value depends on the environmental relative humidity, which has been simplified to M_t/M_0 by some authors [2, 7, 11-14].

The correlation coefficient (r), the reduced chi-square (χ^2), and the root mean square error (RMSE) were used as criteria for adequacy of the fit. The lower the values of the reduced χ^2 , the better is the goodness of the fit. The RMSE gives the deviation between the predicted and experimental values, and it is required to approach zero. These statistical analysis values can be calculated as follow,

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{\text{exp},i} - MR_{\text{pre},i})^2}{N - n} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (MR_{\text{pre},i} - MR_{\text{exp},i})^2}{N}} \quad (3)$$

where $MR_{\text{exp},i}$ represents the experimental moisture ratio found in any measurement; $MR_{\text{pre},i}$ is the predicted moisture ratio for this measurement; and $MR_{\text{exp,mean}}$ is the mean value of the experimental moisture ratio. N and n are the number of observations and the number of constants, respectively [15].

Table I. Mathematical models used to determine the moisture contents of agricultural products during drying processes.

Model	Equation
Page [5]	$MR = \exp(-kt^n)$
Newton [6]	$MR = \exp(-kt)$
Modified Page [7]	$MR = \exp(-(kt)^n)$
Exponential [8]	$MR = a \exp(-kt)$
Logarithmic [9]	$MR = a \exp(-kt) + c$
Two terms [9]	$MR = a \exp(-k_0 t) + b \exp(-K_1 t)$
Verna [10]	$MR = a \exp(-Kt) + (1 - a) \exp(-Kt)$

3. Materials and methods

3.1 Equipment

The equipment used in this work is presented in Fig. 1. The chimney-type solar collector operated in natural convection. The capture surface was 3 m wide and 5 m long. The porous medium made from steel turnings scraps, was 0.20 m thick. The drying chamber dimensions were 0.60 m x 0.60 m x 1.00 m, with three trays for products, separated 0.15 m between them. Product samples were set in a de 0.45 cm x 0.45 cm tray crossed by hot air. It had a 0.005 m-thick crystal cover, separated 0.06 m from the porous media. The trapping surface inclination was 40° with respect to the horizontal plane and was oriented south-north to capture the maximum solar energy.

Air and product-surface temperatures within the drying chamber were measured using 3 calibrated K-type thermocouples with reading accuracy of ± 0.1 °C, located at the entrance of the chamber and another 3, located at the exit. Relative humidity of the environment was determined using an EA25 EXTECH digital hygro-thermometer, with a reading accuracy of $\pm 0.1\%$, which was located outside the solar dryer. An AN200 EXTECH Thermo-anemometer, with a reading accuracy of ± 0.01 m/s, was used to measure the velocity of air, at the exit of the dryer's chimney. The product mass was continuously quantified using a BL1505 SARTORIUS scale, with an accuracy of ± 0.01 g, which was located on top of the drying

chamber. The total solar radiation was measured with a 8-48 EPPLEY pyranometer with a reading accuracy of $\pm 1 \text{ W/m}^2$, located on top of the solar collector and therefore, with the same inclination. All these variables were registered using the Lab-view software in 10 minutes intervals.

3.2 Experimental procedure

Chickpea samples were acquired from Guanajuato State, it is one of the production regions in Mexico. Chickpeas were extracted from the seedpod; each seedpod carried three peas. We selected those with diameters within 9 and 10 mm. The initial weight of the set of selected chickpeas was approximately 100 g. The initial humidity content was approximately 0.52 kg water/kg dry mass (dm). The daily measuring period was from 9:00 to 18:00 hours. The following hours the solar collector was totally covered with a canvas to prevent nightly heat loss. During this period, chickpeas were kept inside a sealed plastic bag within an isolated deposit to preserve its humidity. The following morning experimentation continued, taking care to maintain the same conditions as in the previous day.

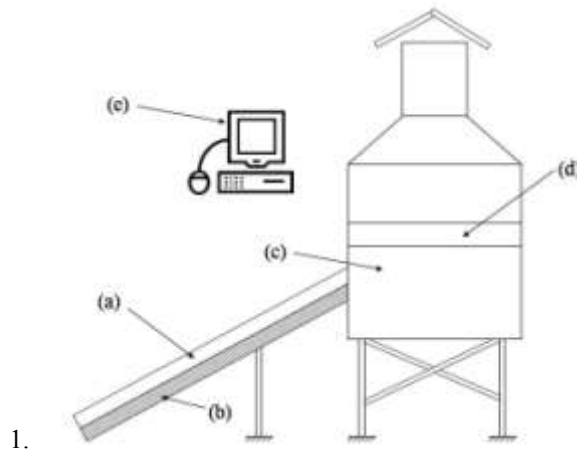


Fig. 1. Diagram of the solar collector, a) capture area; b) porous medium; c) drying chamber; d) three trays for product drying; e) data acquisition system.

4. Results and discussion

The average solar radiation curve as a function of time registered for the month of May, 2012 and its representative equation are presented in Figure 2. The maximum average radiation, 987.4 W/m^2 was observed approximately at 14:00 hours. The corresponding total energy over the collector surface was $6.40 \text{ kW/m}^2\text{h}$.

$$I = -14.48 + 192.78 t + 38.53 t^2 - 9.34 t^3 + 0.37 t^4$$

$$R = 0.997$$

$$SD = 27.69$$

The average temperatures versus the time of the day are presented in Figure 3. The highest temperature at the entrance of the drying chamber was $66.3 \text{ }^\circ\text{C}$; the temperature measured at the product was $63.5 \text{ }^\circ\text{C}$, and at the outlet of the chamber, $58.4 \text{ }^\circ\text{C}$. These values were registered at 14:00 hours and coincided with the value of highest solar radiation. The environmental temperature at the time was $26.8 \text{ }^\circ\text{C}$, which was also the highest value registered during the period of experimentation. The difference in temperature between the inlet and the outlet of the chamber was not constant through the day, early in the morning the

difference was a minimum of 1.4 °C. The highest gradient was registered around 15:00 hours, as 8.7 °C. The temperature at the outlet of the chamber at the end of experimentation was 32.2 °C.

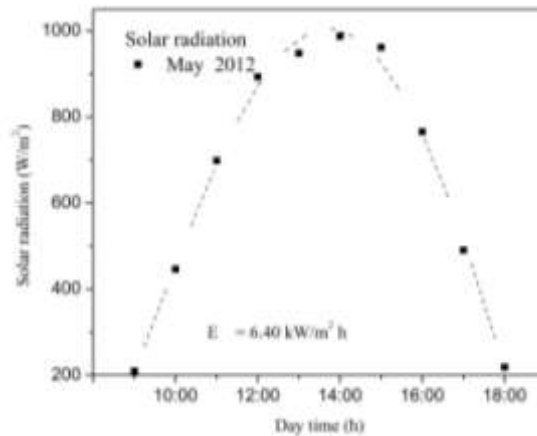


Fig. 2. Average solar radiation in May, 2012.

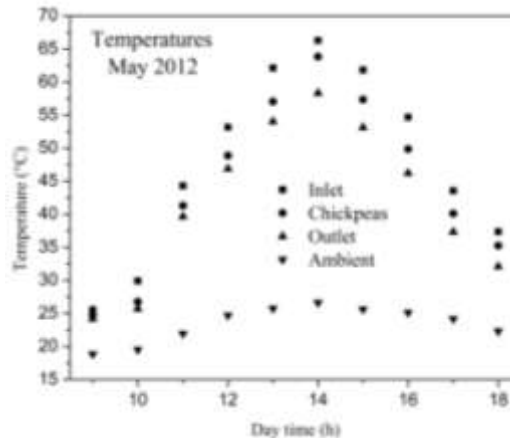


Fig. 3. Average temperatures in the drying chamber and environment, May 2012.

The average mass flow of air registered at the drying chamber is presented in Figure 4. The larger value of mass flow was 0.0276 kg/s and occurred in May, in April it was only 0.0228 kg/s. All of these measures corresponded to a time close to 14:00 hours.

The average of moisture content of the chickpeas was de 0.52 kg water/kg dm (dry mass), at the end of the drying process was of 0.02 kg water/kg dm both experimental months, these results are shown in Fig. 5. In April, it took 40 hours to complete the process whereas in May it only took 32 hours. The drying time was directly dependent on the solar radiation captured on the cover of the drier. At the beginning of the process in both months the mass variation was similar but after 7 hours, the chickpeas lost their humidity at a higher velocity in the month of May, and this difference was kept until the end. The highest drying velocity was 0.186 kg water/kg dm h, and was observed at the beginning of the process; afterwards it remained constant at the value of 0.012 kg water/kg dm h in April, and 0.005 water/kg dm h in May. At this time we could not find reported data to make a sound comparison of results.

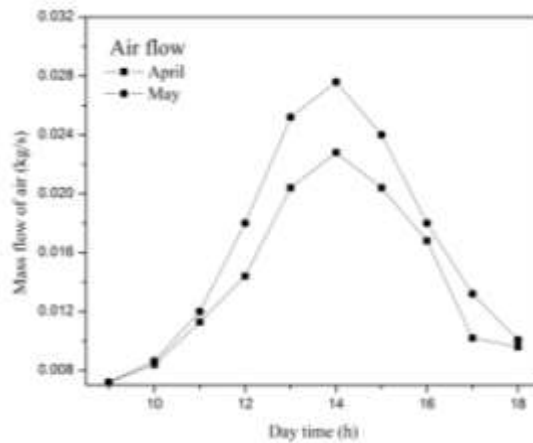


Fig. 4. Average mass flow in the drying chamber.

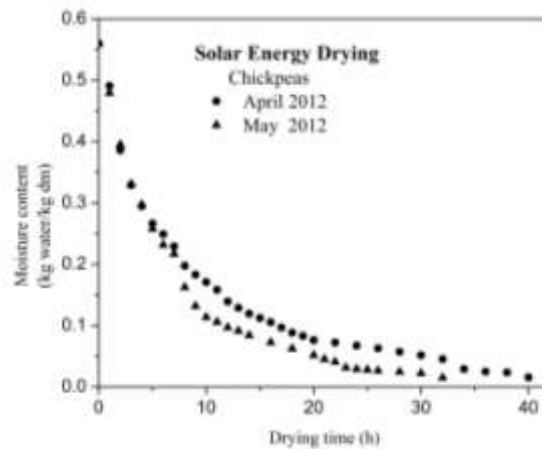


Fig. 5. Moisture contents versus time for Chickpeas.

Experimental data were fed to each of the numerical models presented in Table I. The exponential model described the best the performance of the drying process, complying with the two imposed criteria. The graph of the numeric model obtained for the month of April is presented in Fig.6 and May in Fig. 7.

The equations of the exponential numerical model for both experiments performed are presented in Table II, in all cases this model was the better result for the imposed conditions of r close to the unit, very small values of χ^2 , and small values of the deviation between the predicted and experimental (RMSE).

In the literature, the use of a model to describe drying is very common. The authors assumed that the drying rate in a time t was proportional to the difference between the moisture content at instant t and the equilibrium moisture content. The correlation obtained between the moisture content and the time was implemented in a program to simulate the drying kinetics of the product. The comparison between the experimental and simulated results showed that the correlation obtained satisfactorily describes the drying kinetics for the range of operational conditions considered.

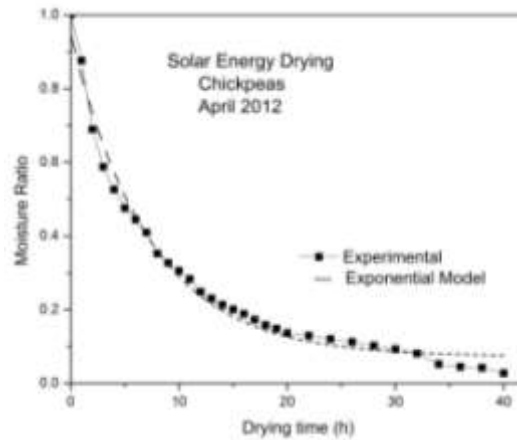


Fig. 6. Numerical model for the drying of chickpeas, April, 2012.

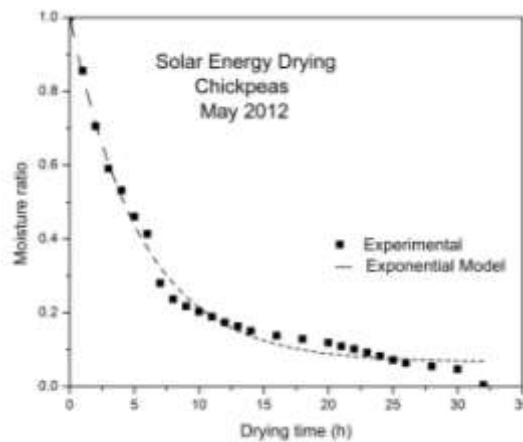


Fig. 7. Numerical model for the drying of chickpeas, May, 2012

Table II. Numerical model of solar energy drying of chickpeas.

Month	Equation $MR = a \exp(-kt)$
April	$a = 0.87259; k = 0.13906$ $r = 0.992; \chi^2 = 0.00083; RMSE = 0.010$
May	$a = 0.93691; k = 0.18427$ $r = 0.994; \chi^2 = 0.00066; RMSE = 0.011$

5. Conclusions

The results observed in this work show that it is possible to dry chickpeas using an indirect-type solar dryer. The studied chickpeas came from Guanajuato State, in Mexico, and had an average moisture content of 0.52 kg water/kg dry mass (dm). At the end of the drying process this content was of 0.02 kg

water/kg dm. The required time to accomplish this drying quality was 40 hours in April and 32 hours in May, 2012. The empirical model that best represented the process was the exponential one, with the three imposed conditions, namely, r close to the unit, a very small χ^2 , and small values of the deviation between the predicted and experimental (RMSE).

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